

# MERIS / ENVISAT FIRST YEAR VICARIOUS CALIBRATION RESULTS FROM RAILROAD VALLEY PLAYA (NV)

Mathias Kneubühler<sup>(1)</sup>, Michael E. Schaepman<sup>(2)</sup>, Kurtis J. Thome<sup>(3)</sup>

<sup>(1)</sup>*Remote Sensing Laboratories (RSL)  
University of Zürich, Switzerland  
Email: kneub@geo.unizh.ch*

<sup>(2)</sup>*Centre for Geo-Information  
Wageningen UR, Wageningen, The Netherlands  
Email: Michael.Schaepman@wur.nl*

<sup>(3)</sup>*Optical Sciences Center  
University of Arizona, Tucson, USA  
Email: Kurt.Thome@optics.arizona.edu*

## INTRODUCTION

The launch of ESA's ENVISAT in March 2002 was followed by a commissioning phase for all ENVISAT instruments to verify the performance of ENVISAT instruments and recommend possible adjustments of the calibration or the product algorithms before the data was widely distributed. Activities to assess the instruments performance are ongoing. This paper presents vicarious calibration results of the Medium Resolution Imaging Spectrometer (MERIS) radiance product (Level 1b) over land, obtained during the instrument's first year of operation. During summer 2002 and 2003, several vicarious calibration (VC) experiments for MERIS were performed by the Optical Sciences Center, University of Arizona, and the Remote Sensing Laboratories, University of Zürich. The purpose of these activities was the acquisition of in-situ measurements of surface and atmospheric conditions over a bright, uniform land target, preferably during the time of MERIS data acquisition. The experiment was performed on a dedicated desert site (Railroad Valley Playa, Nevada, USA), which has previously been used to calibrate most relevant satellite instruments (e.g., MODIS, ETM+, ASTER, Hyperion). In-situ data were then used to compute top-of-atmosphere (TOA) radiances which were compared to the MERIS TOA radiances (Level 1b full resolution product) to determine the in-flight radiometric response of the on-orbit sensor. The mean absolute uncertainties of the vicarious calibration activities lie below 6.72%, but can be reduced to 3.11% by excluding the critical MERIS bands 11 and 15. Based on the uncertainties of the vicarious calibration method and the calibration accuracies of MERIS, no recommendation to update the MERIS calibration is given.

## MERIS

The Medium Resolution Imaging Spectrometer (MERIS) [1] is one of ten instruments on board ESA's ENVISAT platform. MERIS is a 68.5° field-of-view pushbroom imaging spectrometer that measures the solar radiation reflected by the Earth, at a ground spatial resolution of 300 m (full resolution) and 1200 m (reduced resolution), in 15 spectral bands in the visible and near infra-red. MERIS allows global coverage of the Earth in 3 days. MERIS data products provided by ESA include georeferenced TOA radiance data (Level 1b) as well as various water, land and cloud products (Level 2).

Full resolution data sets of the Railroad Valley Playa test site (TOA radiances, Level 1b) from seven different days between August 2002 and July 2003 are investigated. Multitemporal vicarious calibration allows both for monitoring sensor stability and for investigation of the robustness of the vicarious calibration method.

## Railroad Valley Playa Test Site

The dry lakebed of Railroad Valley Playa, Nevada is located at 1.35 km above sea level (38.504° N latitude, 115.692° W longitude). It is a desert site with no vegetation. Temporal records for this site show reflectance variations as a function of time of year, with lowest reflectance in the winter months due to a rising water table. The accuracy of vicarious calibration experiments over land is highly dependent on the choice of an appropriate calibration target. Ideally, such a calibration site should be flat, bright, spatially uniform, spectrally stable over time, near lambertian for small angles off nadir, and of sufficiently large spatial extent. Desert playas are preferred for vicarious calibration of moderate spatial resolution sensors due to their optical properties, predictably sunny conditions and low atmospheric aerosol loading [5].

### Vicarious Calibration

Vicarious calibration is an independent pathway for monitoring instrument radiometric performance, including error assessment with reflectance standards, field instruments and atmospheric radiation measurements. In general, the experiment follows a reflectance-based approach with ground measurements of the atmospheric optical depth and surface reflectance over a bright natural target [2].

In this experiment, in-situ sunphotometer data from six of the seven dates of MERIS data acquisition were available. However, extensive wildfires in California and Oregon led to spatially strongly varying atmospheric conditions during summer 2002. As a consequence, large variations in the atmospheric optical depth must be assumed within small regional extent, depending on whether clouds of smoke were in the line of sight of both the sun photometer or MERIS. Thus, for the 2002 vicarious calibration activities, only the sun photometer data of August 22, 2002 could be used to determine aerosol model and horizontal visibility, subsequently applied for radiative transfer calculation. For the other three dates, large offsets between measured and modelled TOA radiances indicate an inadequate atmospheric characterization.

For the summer 2003 data takes, no untypical atmospheric conditions were observed, but sunphotometer data was only available for two of the three data sets investigated.

In the cases where no sunphotometer data was included in the modelling, a best fitting atmosphere from a LUT (characterized by aerosol model and horizontal visibility) was applied for vicarious calibration. MODTRAN-4 [3][4], a radiative transfer code (RTC) is used, constrained by field data, to calculate the top-of-atmosphere radiance at the sensor. Input parameters include ground measurements of the surface reflectance, sun-target-sensor geometries and atmospheric properties (aerosol model, horizontal visibility).

## EXPERIMENT DATA ACQUISITION

### MERIS Data

Seven full resolution data sets of MERIS, acquired over Railroad Valley Playa between August 2002 and July 2003 were used for vicarious calibration. The data sets are summarized in Table 1.

Acquisition Date	Acquisition Time (UTC)	Orbit Absolute (Relative)	MERIS Camera Nr.	Sun Zenith [°]	Sun Azimuth [°]	Sensor Zenith [°] (off nadir)
August 12, 02	18:17	2357 (299)	1	31.68	132.75	12.06
August 22, 02	18:02	2500 (442)	1	35.16	131.36	12.23
August 31, 02	18:20	2629 (070)	1	36.27	141.95	16.98
October 21, 02	18:17	3359 (299)	1	52.36	157.73	12.06
June 4, 03	18:15	6594 (027)	2	24.54	125.41	8.75
July 9, 03	18:15	7095 (027)	2	25.60	122.51	8.75
July 22, 03	18:06	7281 (213)	4	28.68	121.74	-8.75

Table 1: MERIS Full Resolution data sets (Level 1b) used for vicarious calibration.

MERIS full resolution subsets of Railroad Valley Playa (Nevada) from the seven dates under investigation are given in Figure 1. The symbol identifies the VC test site. The heavy influence of wildfire smoke is clearly visible in the data of August 12 and August 31, 2002.

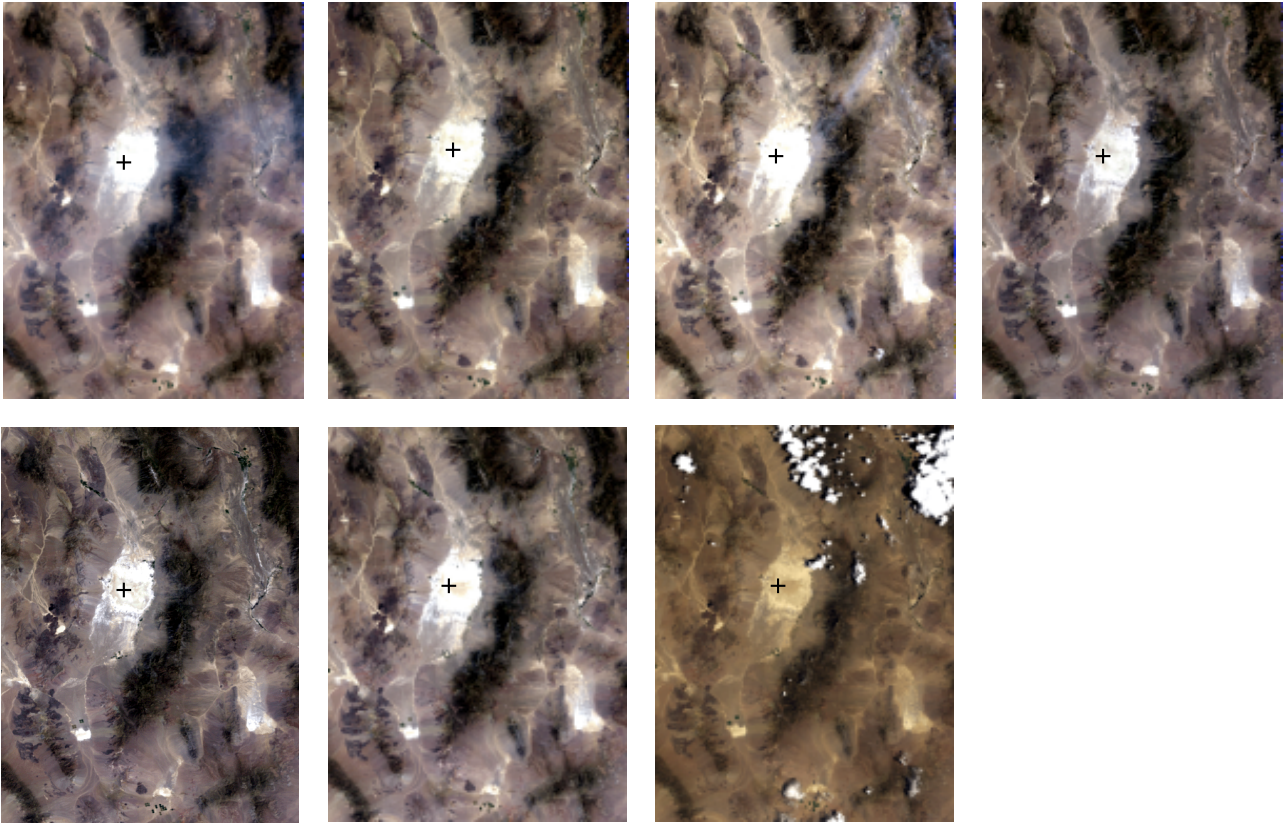


Figure 1: MERIS Full Resolution subsets of the Railroad Valley Playa test site.  
 Top, from left to right: August 12, 2002, August 22, August 31, 2002, October 21, 2002,  
 bottom, from left to right: June 4, 2003, July 9, 2003, July 22, 2003.

### In-Situ Field Measurements

Field data acquisition activities aimed at characterizing (a) the spectral reflectance of the bright surface and, (b) the atmospheric path from the sun to the surface. Therefore, the following ground field instruments were operated in the field:

- An Analytical Spectral Devices, Inc. (ASD) Portable Spectrometer to measure the surface spectral hemispherical directional reflectance factor (HDRF) (only in the nadir view direction) as a function of wavelength in the spectral range between 350 nm and 2500 nm. The variability in the spectral measurements, due to target inhomogeneity and instrument calibration uncertainties is around  $\pm 3\%$  over the 350-1200 nm range ( $\pm 1$  stdev from the mean). Spectral ground truth data was not available for each day of MERIS data acquisition. In these cases, ground truth data, either being acquired closest to the MERIS data takes or representing best recent meteorological conditions at the test site was used. Table 2 lists the spectral ground truth data used for vicarious calibration. As can be seen in Figure 2, reflectance differences exist due to intermediate rainfall.

MERIS acquisition date	Spectral ground truth acquisition date
August 12, 2002	August 15, 2002
August 22, 2002	August 22, 2002
August 31, 2002	August 22, 2002
October 21, 2002	September 21, 2002
June 4, 2003	August 22, 2002
July 9, 2003	July 22, 2003
July 22, 2003	July 22, 2003

Table 2: MERIS acquisition dates and corresponding spectral ground truth used for VC.

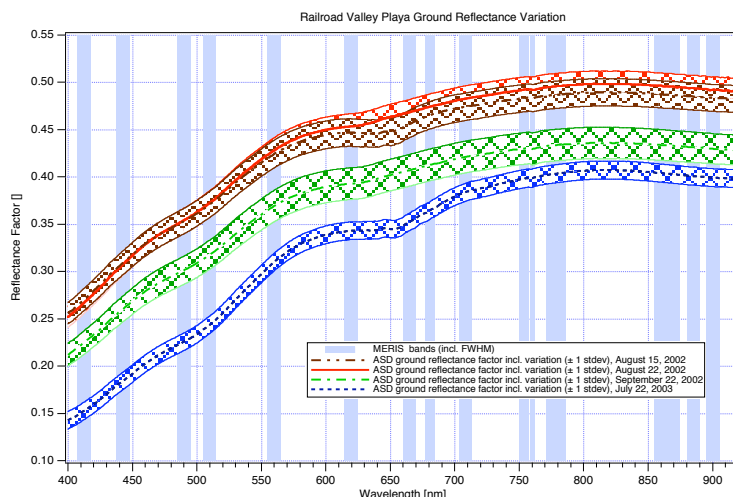


Figure 2: Spectral ground truth data of Railroad Valley Playa used for VC.

- A CIMEL sun photometer to measure the total atmospheric optical depth  $\tau$ . Langley analysis is used to retrieve the aerosol optical depth from these measurements in seven spectral channels in the 400-900 nm range. This instrument makes part of the AERONET network. Sun photometer data was only used if data was available and if the atmosphere was not affected by scattered smoke influence.

## ANALYSIS AND RESULTS

### Radiative Transfer Calculation of TOA Radiance

In a first step, the definition of an appropriate atmosphere, as it was present on the various dates of data take, must be addressed. An analytical approach of deriving atmospheric key parameters from in-situ sun photometer data and radiative transfer code inversion is first applied to all four dates of vicarious calibration. The reference solar irradiance of Thuillier [7], as adopted for ENVISAT by ESA, is used for the atmospheric modelling. The use of MODTRAN standard irradiance data would result in mean deviations of around 4.5% for the radiance calculation over the 400-900 nm wavelength range. Test site location, data acquisition times and dates, as well as the sun-target-sensor geometries are optimized for the specific ground truth area (9 pixels) in the MERIS data sets.

A reasonably low relative rms error (5.943%) for the best fit between MERIS measured and modelled TOA radiances based on sun photometer data inversion could only be achieved for the August 22, 2002 data. The best fitting atmosphere consists of an urban aerosol model and a horizontal visibility of 40 km (see Figure 5). An urban aerosol model accounts best for the unusually high aerosol loading, especially black carbon [6], due to the wildfires. Concerning the three other dates of summer 2002, relative rms errors between 10-20% are observed. Large offsets between measured and modelled TOA radiances are found, indicating an insufficient characterization of the present atmosphere using the sun photometer data. The heterogeneity of the smoke clouds, in combination with the particular sun-target and sensor-target geometries could be possible reasons.

As a consequence, a second approach for vicarious calibration of the multitemporal data set is performed, without the use of any sun photometer data. MERIS measured TOA radiances are compared to the results of various radiative transfer calculations of the ground truth data to TOA radiance, using a look-up table approach. The best fitting atmosphere, characterized by an assumed urban aerosol model and a certain horizontal visibility is then chosen by minimization of the relative rms error.

No presence of smoke from wildfires was observed in the summer 2003 data sets.

### Comparison of Ground Measurements to MERIS Observations

Figure 4 through Figure 10 show the results of the MODTRAN modelled top-of-atmosphere radiances from the spectral ground truth data, together with the MERIS measured radiances in the corresponding MERIS bands for the seven data sets used for vicarious calibration of MERIS over land. It is obvious that the shapes of the modelled curves and the MERIS measured TOA radiances do not fully match, mainly for the 2002 data sets. Especially the first band at 412.5 nm (aerosol type sensitive, strongly affected by heavy smoke of summer 2002 wildfires), band 11 (oxygen at 760 nm)

and band 15 (water vapour absorption region at 900 nm) are critical in the modelling. These bands need more precise atmospheric reference data (e.g., meteorological data) for vicarious calibration. Apart from these bands, the relative differences between MERIS measured and radiative-transfer modelled TOA radiances, as they are given in Table 3, do not exceed 6% (except for band 2 on October 21, 2002).

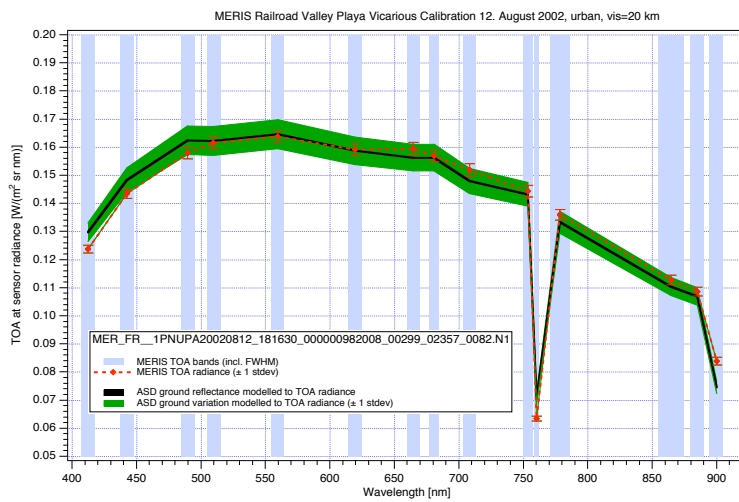


Figure 4: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for August 12, 2002.

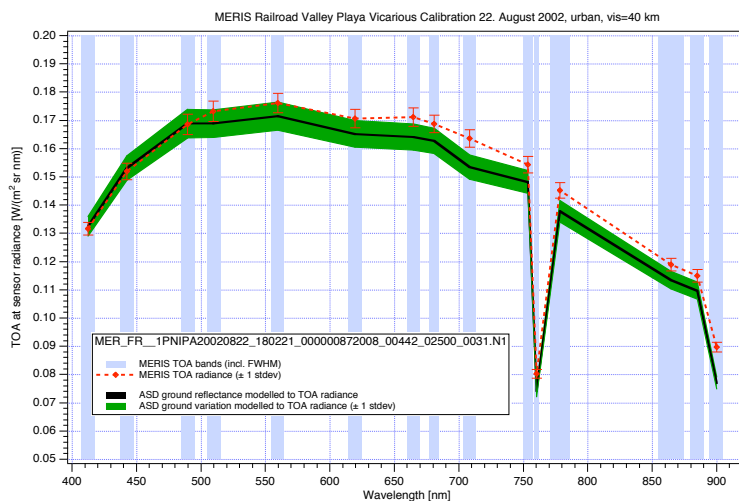


Figure 5: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for August 22, 2002.

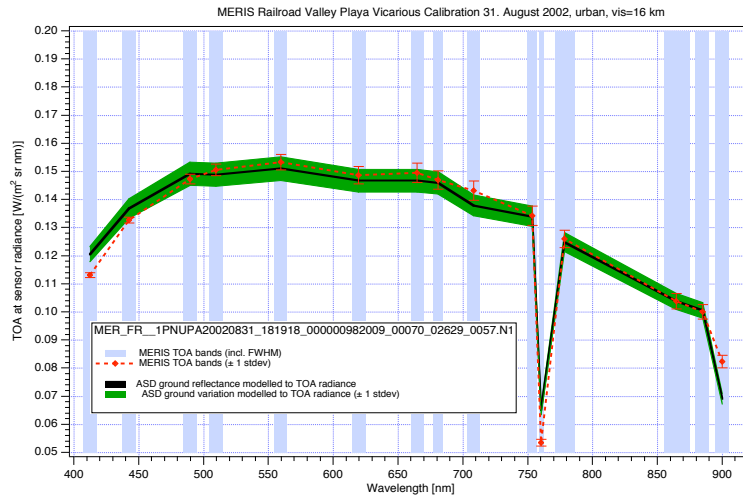


Figure 6: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for August 31, 2002.

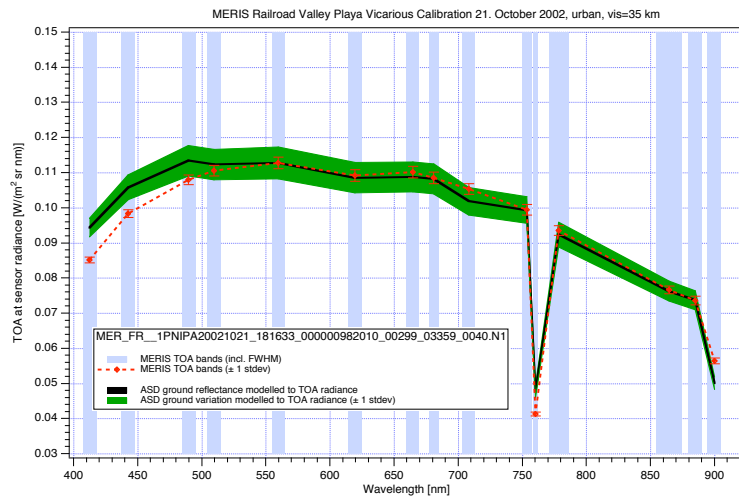


Figure 7: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for October 21, 2002.

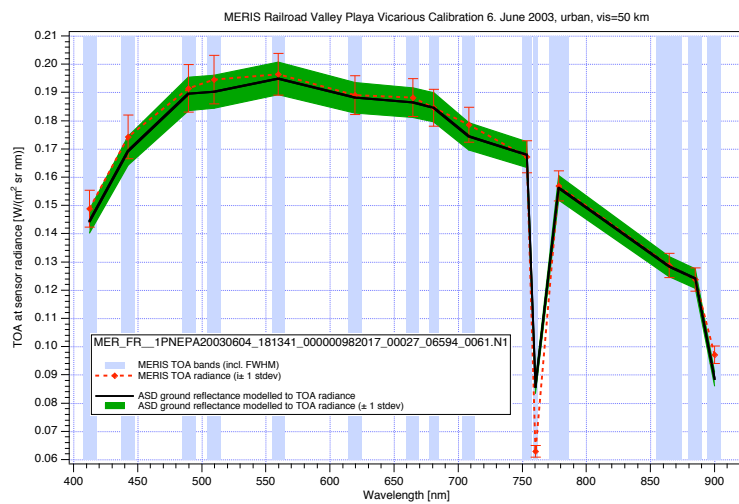


Figure 8: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for June 4, 2003.

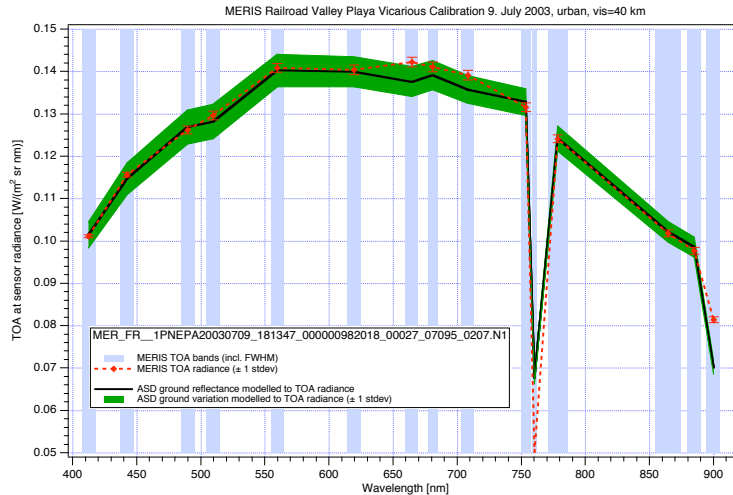


Figure 9: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for July 9, 2003.

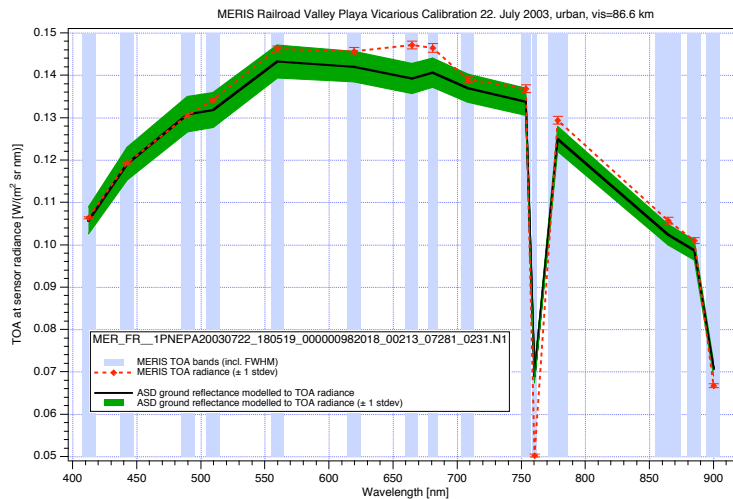


Figure 10: MERIS measured and MODTRAN modelled top-of-atmosphere radiance for July 22, 2003.

In addition to the bandwise relative differences between MERIS measured and MODTRAN modelled TOA radiances, the mean relative rms errors between measured and modelled radiances for all seven dates under investigation are given in Table 3. By excluding the before-mentioned bands 11 (760.35 nm) and 15 (899.86 nm), the relative rms error can be reduced substantially. The mean relative rms error represents the overall uncertainty of the vicarious calibration method, since all potential error sources account for the quality of the data fit. An error budget is given in Table 4. While the uncertainty in the knowledge of the solar irradiance, the spectralon reflectance, the relative surface BRF and the illumination geometry are well known for the test site [5], the uncertainty of the atmospheric characterization is highly dependent on whether reliable sun photometer data is available or whether a best fitting, but poorly known atmosphere is fitted to the data sets. Surface reflectance errors including errors in geolocation, in-situ sampling, test site inhomogeneity and instrument absolute calibration are not included in this error budget, because they are assumed to be represented by the  $\pm 3\%$  variability of the spectral measurements ( $\pm 1$  stdev from the mean), as indicated earlier.



MERIS channel	Center Wavelength (nm)	Differences between MERIS and modelled TOA radiances from VC (%)						
		12. 8. 2002	22.8. 2002	31.8. 2002	21.10. 2002	4.6. 2003	9.7. 2003	22.7. 2003
1	412.545	-4.879	-0.604	-6.614	-10.879	3.080	-0.330	0.565
2	442.401	-3.360	-0.844	-3.141	-7.658	2.825	0.782	0.138
3	489.744	-2.890	-0.335	-1.267	-5.069	1.024	-0.541	-0.221
4	509.700	-0.394	2.356	1.147	-1.624	2.221	1.161	1.834
5	559.634	-0.469	2.543	1.530	0.054	0.832	0.449	2.080
6	616.620	0.212	3.035	1.325	0.634	0.471	0.353	2.491
7	664.640	1.994	4.028	1.805	1.317	0.912	3.252	5.444
8	680.902	0.359	3.442	0.674	0.298	-0.020	1.337	3.984
9	708.426	2.637	5.884	3.657	3.282	2.287	2.486	1.460
10	753.472	0.857	3.856	0.218	0.097	-0.387	-0.955	2.238
<b>11</b>	<b>760.354</b>	<b>-11.750</b>	<b>6.999</b>	<b>-21.662</b>	<b>-15.637</b>	<b>-36.566</b>	<b>-36.495</b>	<b>-37.510</b>
12	778.498	1.949	5.011	0.941	1.195	0.492	-0.097	3.388
13	864.833	2.098	4.512	-0.026	0.550	0.321	-0.364	3.096
14	899.849	1.562	4.465	-0.436	-0.083	-0.324	-0.950	2.253
<b>15</b>	<b>899.860</b>	<b>11.086</b>	<b>13.230</b>	<b>16.217</b>	<b>11.107</b>	<b>8.779</b>	<b>13.837</b>	<b>-5.902</b>
Mean difference (%) <b>Excl. channel 11 and 15</b>		3.100 <b>1.820</b>	2.685 <b>2.140</b>	4.044 <b>1.752</b>	3.966 <b>2.518</b>	4.036 <b>1.169</b>	4.226 <b>1.004</b>	4.840 <b>2.246</b>
Mean difference (%) <b>Excl. channel 11 and 15</b>		4.690 <b>2.911</b>	5.943 <b>3.783</b>	7.146 <b>3.684</b>	5.953 <b>5.311</b>	7.493 <b>2.013</b>	8.153 <b>1.334</b>	7.641 <b>2.731</b>

Table 3: MERIS and VC TOA radiances differences for the observed dates of data take.

Error Source	Absolute Uncertainty (%)	
	Including all channels	Excluding channels 11 & 15
Solar Irradiance Knowledge	2	
Spectralon Reflectance Knowledge	1.5	
Relative Surface BRDF Knowledge	1	
Atmospheric Characterization max. (mean from all dates)	< 7.74 (6.16)	< 4.58 (1.55)
Cosine of Solar Zenith	< 0.1	
<b>Root-mean-square max. (mean from all dates)</b>	<b>&lt; 8.15 (6.72)</b>	<b>&lt; 5.31 (3.11)</b>

Tab.4: Vicarious calibration error budget.

## CONCLUSIONS

Reflectance-based vicarious calibration methods generally have absolute uncertainties of 3-5% [8]. It is obvious from this study, that an accurate characterization of the atmosphere during a vicarious calibration experiment is crucial. The absolute uncertainty of this study's VC activities is below 8.15% (mean of all dates under investigation: 6.72%), based on all MERIS channels. Under exclusion of channels 11 and 15, the method's uncertainty can be reduced to under a maximum of 5.31% (mean of all dates under investigation: 3.11%).

The mean differences between MERIS- and VC- mean TOA radiances do not exceed 5% for any of the dates under investigation. Exclusion of band 11 and band 15 results in mean differences lower than 2.5% for all data sets. Apart from band 1 (sensitive to aerosol type, 412.55 nm), band 11 (oxygen band at 760 nm), and band 15 (water vapour absorption region at 900 nm), all bandwise VC results lie within less than 6% of MERIS measured TOA radiances



(except for band 2 on October 21, 2002 ). These bands need very precise atmospheric characterization for VC. An incorrect assumption about aerosol absorption can strongly affect the VC accuracies of the shorter wavelengths bands. During summer 2002, North American wildfires strongly altered the type of atmosphere generally present at the test site. More stable atmospheric conditions were observed for the summer 2003 data sets.

Stable atmospheric conditions over a certain regional extent and radiative transfer model inversion including non-standard aerosol models (e.g., the influence of black carbon particles) could further improve VC results.

From the results of this multitemporal VC experiment, no need to update the MERIS calibration may be formulated. Although differences between measured and modelled TOA radiances greater than 6% occur in several bands, the uncertainties of the VC method and the accuracy requirements of MERIS absolute radiometric calibration (< 6%) do not allow to suggest a calibration update. Nevertheless, multitemporal VC, supported by extensive ground truth data collection, bears the potential to monitor the radiometric performance of a sensor over time. Surface HDRF measurements using a goniometer could improve the VC of large field-of-view sensors, since an off-nadir geometry could be modelled more precisely when using directional reflectance data other than from nadir. Spectrodirectional ground truth should be acquired as close to the time of the sensor overflight as possible, in order to minimize vicarious calibration errors due to temporal surface reflectance changes.

Based on the findings of this study, a need for a VC experiment in a very large and spectrally homogeneous area (eg., Erg Murzuk (Libyan Sahara)) with stable atmospheric conditions is expressed. The supposed uniform test site should preferably fill the complete field-of-view of the five MERIS cameras, in order to satisfactorily address the individual camera behaviours and directional effects.

## ACKNOWLEDGEMENTS

These activities were supported by the Swiss Federal Office for Education and Science in the framework of CH-Intex (Nationaler Unterstützungskredit an internationale Experimente) and the University of Zürich. The on-site support of the Remote Sensing Group of the University of Arizona is greatly acknowledged.

## REFERENCES

- [1] EUROPEAN SPACE AGENCY, *MERIS PRODUCT HANDBOOK*, pp:570, 2002.
- [2] WEDAD, A., C. J. BRUEGGE, M. C. HELMLINGER, J. E. CONEL, S. H. PILORZ, W. LEDERBOER, B. J. GAITLEY, AND K. J. THOME, *VICARIOUS CALIBRATION EXPERIMENT IN SUPPORT OF THE MULTI-ANGLE IMAGING SPECTRODIAMETER*, IEEE TRANS. ON GEOSC. AND R.S., 40(7):1500-1511, 2002.
- [3] BERK, A., L. S. BERNSTEIN, AND D. C. ROBERTSON, *MODTRAN: A MODERATE RESOLUTION MODEL FOR LOWTRAN7*, AFGL TECHNICAL REPORT, GL-TR-89-0122, HANSCOM AFB, MA, pp:38, 1989.
- [4] BERK, A., G. P. ANDERSON, P. K. ACHARYA, J. H. CHETWYND, L. S. BERNSTEIN, E. P. SHETTLE, M. W. MATTHEW, AND S. M. ADLER-GORDON, *MODTRAN4 USER'S MANUAL*, ABREU L. W. AND ANDERSON G. P. (EDS.), AIR FORCE RESEARCH LABORATORY, SPACE VEHICLES DIRECTORATE, HANSCOM AFB, MA, pp:97, 1999 (REVISED APRIL 2000).
- [5] BRUEGGE, C. J., N. L. CHRIEN, R. R. ANDO, D. J. DINER, W. A. ABDU, M. C. HELMLINGER, S. H. PILORZ, AND K. J. THOME, *EARLY VALIDATION OF THE MULTI-ANGLE IMAGING SPECTRODIAMETER (MISR) RADIOMETRIC SCALE*, IEEE TRANS. ON GEOSC. AND R.S., 40(7):1477-1492, 2002.
- [6] KAUFMAN, Y. J., D. TANRÉ, AND O. BOUCHER, *A SATELLITE VIEW OF AEROSOLS IN THE CLIMATE SYSTEM*, NATURE, 419:215-223, 2002.
- [7] THUILLIER, G., M. HERSÉ, P.C. SIMON, D. LABS, H. MANDEL, D. GILLOTAY, AND T. FOUJOLS, *THE SOLAR SPECTRAL IRRADIANCE FROM 200 TO 2400 NM AS MEASURED BY THE SOLSPEC SPECTROMETER FROM ATLAS 1-2-3 AND EURECA MISSIONS*, SOLAR PHYS., 214 (1): 1-22, 2003.
- [8] THOME, K. J., *ABSOLUTE RADIOMETRIC CALIBRATION OF LANDSAT-7 ETM+ USING THE REFLECTANCE-BASED METHOD*, REMOTE SENS. ENVIRON., 70:27-38, 2001.